Calibration of the Koyukuk River Basin Above Hughes, Alaska

Eric Anderson, May 2005

Introduction

The calibration of the Koyukuk Basin was done in support of the Alaska-Pacific River Forecast Center (APRFC). The Koyukuk Basin is located in north central Alaska. The Koyukuk originates on the southern slopes of the Brooks Range within the Gates of the Artic National Park and eventually enters the Yukon near the village of Koyukuk, just downstream from Galena. The calibration is based only on the drainage area above Hughes (18,700 sq. mi.) for two reasons. First, the only historical streamgage data are at Hughes and a few points upstream. Second, significant flooding hasn't been reported below Hughes.

Runoff in the Koyukuk Basin is primarily due to snowmelt in the late spring and frequent summer rains. Much of the summer storms are convective in nature and only affect portions of the basin, but once in awhile a large general system will generate runoff throughout the drainage. A major flood was produced by a sequence of two such storms in August 1994. A peak of 34.6 feet occurred at Hughes (330,000 cfs - estimated by the USGS). This was a very devastating flood. The villages of Allakaket and Alatna had especially heavy damage, with many structures washed away and the eventual relocation of the villages (Meyer and Lindsey, 1995). In August of 1937 the flood peak reached a stage of about 34 feet, based on information from local residents as noted in the USGS Water Resources Bulletin.

One of the main challenges for the calibration effort was the lack of data. USGS streamflow records are only available at 5 sites. These are:

- Koyukuk River at Hughes (15564900) – June 1960 to September 1982
- Middle Fork nr Wiseman (15564875 – 1200 sq. mi.) August 1979 to September 1978 and October 1983 to September 1987
- Jim River nr Bettles (15564885 – 465 sq. mi.) August 1970 to September 1977
- Wiseman Ck at Wiseman (15564877 – 49.2 sq. mi.) August 1970 to September 1978
- Slate Ck at Coldfoot (15564879 – 73.4 sq. mi.) May 1995 to current.

There are also some manual daily stage readings starting around 1970 for the mainstem at Bettles and Allakaket and in the late 1990's for the Middle Fork streamgage location that were supplied by the APRFC.

The historical precipitation and temperature station records for the Koyukuk Basin are also quite sparse. Fortunately there is one station centrally located within the basin with a long data record. This is the NCDC Climatological station at Bettles. Most of the other stations have much shorter periods of record with periodic times of missing data. The periods with the best data are from about 1970 to 1977 when the Trans-Alaska pipeline was being constructed through the eastern edge of the basin and in recent years with the addition of some SNOTEL and RAWS automated stations. There were no hourly precipitation data records until October 1962 and that is at Fairbanks which is located about 115 miles southeast of the southern tip of the basin. The most recent "final" data for the SNOTEL sites ended in September 2002 though some NCDC and RAWS data were available beyond that date. For these reasons the historical period of record selected for the calibration is water years 1963 to 2002.

A CD has been prepared to go along with this report. The CD contains all the data used in the calibration, plus spreadsheets containing some of the analysis and scanned copies of some plots. A complete description of the contents of the CD is contained in Appendix A.

Basin Description

The Koyukuk Basin covers an area from roughly 66 to 68 degrees latitude and 149 to 155 degrees longitude. Elevations range from 250 feet at Hughes to 7457 feet near the divide within the North Fork drainage. The Endicott Mountains (part of the Brooks Range) extend across the northern half of the basin. Most of this portion of the basin consists of vast and essentially untouched areas characterized by glaciated valleys and rugged mountains within the Gates of the Artic National Park (www.nps.gov/gaar). Based on information from the Gates of the Artic National Park web site, the taiga, or boreal forest reaches its northern limits at about 67.5 degrees latitude along the south slope of the Brooks Range. The extensive forest cover follows the river valleys into the mountains up to an elevation of about 2100 feet. On south slopes the forest consists primarily of white spruce and hardwoods, such as birch and aspen, with heaths and willows quite common and lichens and mosses covering the forest floor. On the north slopes black spruce are predominant with an understory of spongy moss and low brush. Above the tree line shrub thickets exist up to about 3000 feet. On the slopes dwarf birch, willows and alders, heath type shrubs, and patches of tundra are typical. Along the alluvial plains at these elevations willows and alders predominate. Above 3000 feet the vegetation is tundra consisting of mosses, lichens, heathers, and grasses. The web site indicates that within the park the soils in the mountains are mostly thin, poorly drained, sandy soils. At lower elevations a silty loam is overlaid by a peat layer. Throughout the park the soils overlie a thick, continuous permafrost layer that sometimes is within a few inches of the surface.

A large part of the southern portion of the basin lies within the Kanuti National Wildlife Refuge (http://kanuti.fws.gov/). The Kanuti National Wildlife Refuge is covered in large part by boreal forest. The forest overlies discontinuous areas of permafrost. Black and white spruce are the predominate tree species with other areas containing alder, birch, and willows. White spruce, birch, aspen, and balsam poplar are found on well drained riparian and upland locations. Black spruce are found on poorly drained soils. The boreal forest is interspersed with numerous water bodies ranging from rivers and streams to lakes, ponds, and wetland areas within the refuge. Elevation on the refuge ranges from 400 to 3000 feet including rolling hills, river flood plains, and wetlands with tundra existing over parts of the higher elevations.

The Dalton highway and the Trans-Alaskan pipeline run along the eastern portion of the basin and provide the only land access to the area. Villages located along the highway include Coldfoot and Wiseman. The highway and pipeline cross the Brooks Range at Antigun Pass. The other villages within the Koyukuk Basin are located along the river including Bettles, Allakaket, and Hughes. Figure 1 shows a map of the Koyukuk Basin along with the Gates of the Artic National Park and the Kanuti National Wildlife Refuge.

The Koyukuk Basin is characterized by very cold winters and moderately warm summers at lower elevations with less seasonal variation at the higher elevations. The average high and low temperature for January at Bettles (640 feet) is -4˚F and -20˚F, respectively while at Antigun Pass (4800 feet) for January the average maximum is -2˚F and the average minimum is -11˚F. An inversion is prevalent within the basin from November into March below about 2000 to 3000 feet. In July the average high and low for Bettles is 70˚F and 49˚F while for Antigun Pass the average max and min are 49˚F and 39˚F.

Most precipitation is in the form of snow from October through April with snowfall common in September and May at higher elevations. The snow cover generally persists into late May or early June at lower elevations and well into June in the mountains. The greatest amounts of precipitation occur in the summer with the peak in August for most stations. Snow data are available at a number of sites in and near the basin. Water equivalent data are available on a daily basis for the Coldfoot SNOTEL site and a SNOTEL installation at Bettles (the Bettles site has no telemetry and its data are not available via the NRCS web site). A snow depth sensor has also been installed at the Coldfoot SNOTEL site in recent years. There are also several snow courses in the area including one at Bettles. Snow depth and snowfall data are available at most of the NCDC climatological stations used for the calibration, with the longest records available at Bettles and Chandlar Lake.

Subdivision of Basin

For the calibration effort the USGS headwater gage locations for the Middle Fork at Wiseman and the Jim River near Bettles were used. The remainder of the basin was divided into sub-drainages where each major tributary entered the mainstem. Local areas were established for the mainstem locations with daily flow or stage records; Bettles, Allakaket, and Hughes. Each drainage area was then subdivided into elevation zones. An elevation of 2100 feet was used to separate the lower and upper zones. Thus, the lower zones represent the boreal forest and the upper zones contain shrub thickets and tundra. Table 1 summarizes the breakdown of the basin into individual drainages and shows the drainage areas and the fraction of each area that is within the lower elevation zone. The sub-basins used in the calibration are also shown on Figure 1. USGS drainage areas were used for the Middle Fork, the Jim River, and the Koyukuk at Hughes. Scott Lindsey of the APRFC computed drainage areas for each sub-basin using a GIS. For all the intermediate drainages between the Middle Fork and the Jim River and Hughes, the GIS calculated areas were used to prorate the USGS specified drainage area (18,700-1200-465=17,035 sq. mi.). These computations are included in the Basic Information Summary.xls file on the CD.

Historical Data Analysis

Mean Areal Precipitation (MAP) and Temperature (MAT) time series were generated for each of the sub-basins and elevation zones within the Koyukuk Basin for use in the calibration. In addition, ET-Demand estimates were derived for each area.

Precipitation

Table 2 shows the station data available for the Koyukuk Basin. Most of the data are from the NCDC climatological network. Four of the stations are NRCS SNOTEL stations (ATGA2, COFA2, GOBA2, and TOOA2). Five of the stations are BLM RAWS sites that only provide data during the late spring and summer. These sites are NRUA2, KANA2, HOGA2, HOZA2, and KOYA2. A few of the NCDC stations had an additional short period of data besides the primary period listed in Table 2. These are Allakaket (Nov. 97 – May 98), Prospect Creek (Oct. 99 – Apr. 01), Rampart 2 (Oct. 75 – Jul. 77), and Wild Lake 2 (Jul. 75 – Feb. 76).

Scott Lindsey provided PRISM estimates of the mean monthly precipitation at each site for the WY 1961-1990 period. The PXPP program was used to determine consistency corrections. Hughes was the only station that required any corrections. PXPP was then used to calculate monthly averages for 3 different periods. First, means were computed for a period that encompassed the entire period of available precipitation data, WY 1952-2002. PXPP was also used to generate estimates of monthly averages for the PRISM period and for the historical period of record used for the calibration. Table 3 shows the seasonal averages from the PRISM data and the ratio of the PXPP average to the PRISM average for the WY 61-90 period for those stations with sufficient data during that period to compute monthly averages. The winter season was from October through April and the summer season from May to September.

The average PXPP/PRISM ratio for the stations shown in Table 3 is quite close to 1.0 for both the winter and summer. Table 3 also shows the ratios of the PXPP computed means for the WY 63-02 period to the WY 61-90 period. These ratios are close to 1.0 as are the same ratios for WY 51-02 compared to the WY 61-90 period (average annual ratio was 1.01). This indicates that the average precipitation for each of the periods were essentially the same. Based on these comparisons, it was decided that the PRISM values were a reasonable estimate of the precipitation over the basin and therefore, the PRISM data could be used directly to determine the average seasonal precipitation for each sub-basin and elevation zone for the historical period of record.

For computing MAP the station means determined for the WY 52-02 period with PXPP were used for most stations. These means were used because this was the period for which there were sufficient data to compute monthly averages for almost all the stations. Monthly means couldn't be computed for Coldfoot (CDXA2 - NCDC 50-2104) and the Mile 42 Steese hourly gage. Coldfoot was assigned the same monthly values as the Coldfoot SNOTEL site and Mile 42 Steese used the values for Keystone Ridge. Also mean monthly values couldn't be computed for the winter months for any of the RAWS sites. In this case the PRISM monthly values were used for the winter months. In addition, the KANA2 and KOYA2 RAWS sites appeared to under catch precipitation. For these two stations the PRISM averages were also used for the summer months and adjustments applied to the data so that the long-term summer average would be the same as estimated by PRISM. These adjustments were 1.36 for KANA2 and 1.67 for KOYA2.

When working with the data a number of problems were encountered. For the SNOTEL sites the DATACARD format images obtained from the NOAA Hydrologic Data System (NHDS) contained frequent periods of missing values followed by a large amount. It was assumed that these should have been coded as missing time distribution with the value at the end of the period being the accumulated total. For short periods the missing values (-999.0) were changed to indicate missing time distribution (-998.0). For longer periods that extended over multiple months the total at the end was set to missing (for the 1994 flood event for the ATGA2 site an accumulated total for the last half of August was estimated from the reported mid-August to mid-September total – the average ratio between ATGA2 and TOOA2 for that time of year was used to estimated how much of the precipitation fell in September and the remainder was assumed to be the accumulated total for the last part of August). Both daily and hourly data were available for much of the period of record at the RAWS sites, however, the periods of data provided by the APRFC at each site weren't the same. These records were manually compared and changed so that the data are now consistent. This primarily involved setting zero precipitation in the hourly records to missing to match the reporting periods in the daily records, though in some cases zero values in the daily records needed to be set to missing to match the reported hourly values. In addition to these problems, there were some cases where individual data values clearly appeared to be in error at NCDC sites based on comparisons with nearby locations. In these cases the value was either changed when the type of error seemed evident or set to missing. All of the precipitation data edits are noted in the README.edits file in the station precipitation data directory on the CD. In addition to these problems the NHDS indicated that there was hourly precipitation data for Tanana AP, however, when these data were downloaded with the HLYTRAN program, the entire record contained zero values. Thus, this hourly station was not used.

Seasonal predetermined station weights were used when generating the MAP time series for each area in the basin. As mentioned, the historical period of record seasonal areal average for each of the MAP areas was obtained from PRISM and the station seasonal averages primarily from the WY 52-02 PXPP run. Relative weights were subjectively assigned. The Koyukuk_precipitation_analysis.xls file contains the station weight computations for each of the MAP areas within the basin.

When checking the consistency of the data with the MAP program, it was noted that the estimates of missing data at the hourly and daily RAWS sites were quite different. The total over the historical period of record for each daily station was only about half of that for the hourly gage at the same site. The problem was determined to be caused by computational logic in the MAP program and the fact that for much of the historical period of record the only available hourly gage is Fairbanks. To solve this problem the hourly stations were moved away from the basin to surrounding locations that still provide about the same relative weighting for time distributing daily amounts. When this was done, another problem popped up. A couple of the hourly stations were set to zero for all periods with missing data. It turned out that the MAP program sets missing values to zero when the station being estimated is too far away from the available estimators. In this case Fairbanks was the only available estimator. To solve this problem a duplicate Fairbanks hourly station was placed on the north side of the basin, but beyond where the RAWS hourly gages were moved. Figure 2 shows the locations that were used for each of the gages when computing MAP values.

Temperature

Daily maximum and minimum temperatures used to compute MAT were from many of the same stations as listed in Table 2 for precipitation. Stations that were not used for temperature computations are Anaktuvuk Auto, Coldfoot, Fairbanks, Hog River, Huslia 50 NW, Keystone Ridge, and Mile 42 Steese. The period of record for those stations that were used was essentially the same as noted in Table 2 for precipitation except for the ATGA2 and TOOA2 SNOTEL sites (for the RAWS sites the temperature record is the same as the daily precipitation record). For ATGA2 the temperature record began in August 1992 and at TOOA2 in July 1994. In addition, max-min temperature data were also available from the APRFC for Indian Mountain (PAIM) from Aug. 1995 through the end of the historical period of record. The more recent Indian Mountain data was treated as a separate station from the earlier record obtained via NCDC. The only editing of temperature data was for the Coldfoot SNOTEL site. A number of max and min values that were clearly in error were changed to a reasonable value or set to missing for that station (these are noted in the max/min data files for Coldfoot). In addition to the station data, max-min values were also available at multiple upper air levels from 5 locations derived from the results of the NCEP/NCAR Reanalysis Project and from the Fairbanks radiosonde. Dave Streubel of the APRFC produced the max-min values for the Reanalysis sites. The sites were at the following latitude/longitude locations: 67.5/150, 67.5/152.5, 67.5/155, 65/147.5, and 65/155. Max-min values at the Reanalysis sites were generated for elevations near the surface and at 4800 and 8000 feet. For the Fairbanks radiosonde daily max-min values were provided at 1000, 3000, 5000, and 8000 feet.

Several of the temperature stations had inconsistencies in their record. Corrections were applied at one point within the period of record for Allakaket, Prospect Creek, Tanana AP, Wild Lake 2, Coldfoot SNOTEL, and Norutak Lake. No corrections were needed for the Reanalysis and radiosonde data.

Average monthly max and min temperatures for the historical period of record were computed directly from the data for the Reanalysis sites and the radiosonde data since there were no missing values. For the station data there were only two locations with data for most of the historical period of record. These were Bettles and Tanana AP. Since NWSRFS doesn't have a preliminary processing program for temperature that computes monthly averages in a consistent manner like PXPP does for precipitation, average monthly max and min values had to be computed manually with the aid of a spreadsheet for all the other stations. This was done by calculating mean monthly max and min values for each station for its period of record and for Bettles for the same period. The differences between the station values and Bettles for this period were then applied to the Bettles averages for the entire historical period of record in order to get an estimate of the station average max and min for the historical period of record. These computations are in the Koyukuk_avg_temps.xls file.

The average monthly temperatures for those stations closest to the basin, as well as the latitude 67.5 Reanalysis locations and the Fairbanks radiosonde, were used to develop max and min temperature versus elevation relationships for each month (the RAWS temperature data were not available when the analysis was done). Previous analyses at the APRFC had shown that the mean monthly temperatures (average of max and min) from the Reanalysis data were essentially the same throughout the year as observations at high elevations though the spread between max and min was greater at the surface measurement sites (such comparisons were made for the Gulkana Glacier at 4850 feet and the Wolverine Glacier at 3250 feet). For the Koyukuk Basin comparisons between the Reanalysis data at 4800 feet and the Antigun Pass SNOTEL site, also at 4800 feet, only showed the daily means to be essentially the same from May through August (the spread was greater for ATGA2 than indicated by the Reanalysis data as in the case of the glacier sites). During the rest of the year the temperatures at Antigun Pass were colder than for the Reanalysis data by as much as over 10˚F in December and January. The temperature versus elevation relationships developed for the Koyukuk Basin were primarily based on station data with the Reanalysis data used during some months as a guide. The Reanalysis data showed inversions somewhere between 2000 and 4800 feet during all months except July and August (also no inversion for max temperature in June). The station data only indicated that an inversion existed from November through February for max temperatures and November through March for min temperatures. The inversion level varied between 2100 and 3000 feet. The Fairbanks radiosonde data only indicated an inversion from November through February (the radiosonde data showed less spread between max and min values than even the Reanalysis data). The inversion level based on the radiosonde data appeared to be somewhere in the 3000-4000 foot range. The initial lapse rates (above the inversion level) were subjectively determined using monthly plots of temperature versus elevation. These were plotted versus time of the year and then smoothed to get the final values. Figure 3 shows the initial and final lapse rates for max and min temperatures. Lapse rates derived from the station data were similar to those based on the Reanalysis data in the middle of the winter, but were significantly greater in the summer. Scanned copies of the temperature versus elevation plots for each month are included on the CD.

The established temperature versus elevation relationships were used to establish mean monthly max and min temperatures for synthetic, "dummy", stations at the mean elevation of each MAT area. MAT time series were then generated for each area using all the station data, plus most of the Reanalysis and radiosonde data. These were the time series used for the model calibration. When the calibration was complete, two additional sets of MAT time series were produced for comparison purposes. One set utilizes only station data and the other set just uses the Reanalysis data. The same mean values are used for the synthetic stations in all cases.

Evaporation

ET-Demand estimates were derived for each of the sub-basins and elevation zones as follows:

1. An annual PE versus elevation relationship was developed using annual PE values computed using the Thornthwaite method (Patric and Black, 1968) for a number of locations in the general vicinity of the Koyukuk Basin. This relationship showed annual PE varying linearly from just over 18 inches at around 200 feet to just under 8 inches at 4000 feet.
2. Monthly PE values were determined for 4 sites based on pan data. These sites were McKinley Park, University Experiment Station, Tanana, and Rampart 2. A pan coefficient of 0.8 was used to convert the pan values to PE.
3. Based on the seasonal shape of the PE estimates at the 4 pan sites and the annual PE versus elevation relationship developed in step #1, monthly PE curves were derived for elevations of 500, 1500, 2500, and 3500 feet.
4. Seasonal PE adjustment curves were subjectively defined for the 4 elevations used in step #3. These curves were based on the type of vegetation that generally exists at each of the elevations. The peak PE adjustments during the height of the growing season varied from 1.1 at 500 feet to 0.5 at 3500 feet.
5. The monthly PE values at each of the 4 elevations were multiplied by the monthly PE adjustments to get a monthly value of ET-Demand. These values are shown on Figure 4.
6. For each sub-basin and elevation zone an ET-Demand curve was derived by linearly interpolating between the appropriate curves developed in step #5 based on the mean elevation of the area.

The data and steps 1-5 of the evaporation analysis, including plots, are shown in the Evaporation Analysis.xls file on the CD. Step 6 is included in the Basic Information Summary.xls file. No changes were made to the ET-Demand estimates during the course of the calibration.

Model Calibration

The strategy that was followed for calibrating the various models to the Koyukuk Basin was to first perform a calibration for the two larger headwaters that had historical mean daily flow records; the Middle Fork near Wiseman (MFKA2) and the Jim River near Bettles (JMRA2). Next the parameters developed for these two drainages were applied to the remainder of the basin so that a comparison of simulated and observed discharges at Hughes could be made for the period that USGS daily flows were available. The plan was to then make simple parameter modifications to correct for volume or timing errors. It turned out that only routing model parameters needed any adjustments. The initial headwater calibration and total basin flow simulation was first done using precipitation and temperature data only from the NCDC and SNOTEL stations. RAWS precipitation and temperature data, as well as manual daily stage readings for Allakaket, Bettles, and the Middle Fork, were not available until near the end of the calibration effort. The addition of the hourly precipitation data at the RAWS sites helped get a better estimation of the rainfall intensity during summer storms. Initially the time distribution of daily totals into 6 hourly amounts was essentially based entirely on hourly data at Fairbanks. This created unrealistic intensity patterns during many events. The shape of the simulated instantaneous hydrographs changed for those events when the RAWS hourly data were added. The availability of daily stage data allowed refinements to be made to the routing parameters and made a comparison of simulated and observed flows possible at the intermediate points of Bettles and Allakaket.

Prior to beginning the calibration a comparison of the response from the various sites with USGS streamflow records was made. The flow records for each site were adjusted to a common drainage area so that the response of the different drainages could be easily compared. The following conclusions were drawn from this comparison:

1. The Jim River and Slate Creek (SLAA2) flows were flashier than those for the Middle Fork and Wiseman Creek (most of Wiseman Creek is above 2100 feet though the exact amount wasn't derived). This was apparent both during snowmelt runoff and summer storms.
2. There were discrepancies between the responses from the different locations early in the snowmelt period during some years (this comparison could only be made for water years 1970-77 when streamflow data were available for multiple sites). This was attributed to ice affecting the ability to make good measurements or any measurements at all. The USGS Water Resources Bulletins for these stations indicates that there are no gage-height values available during the winter and into the early part of the melt season during most years, thus the records are poor since the flows are estimated. The Middle Fork response was especially deficient for water years 1970 and 1971, thus it was decide not to use these two years at the beginning of the period of record when calibrating MFKA2.
3. The baseflow values that were estimated by the USGS from late fall until early spring when there were no gage-height measurements are quite erratic. It was decided to generally ignore these winter low flow estimates during the calibration.

The Middle Fork was calibrated first since it had the longer period of record. Since the most of the Middle Fork was above 2100 feet (85% in the upper elevation zone) any differences in parameter values between the upper and lower elevation zones couldn't be determined. Thus, initially the upper and lower zone snow and soil moisture parameters for MFKA2 were kept the same. Since 59% of the Jim River basin was within the lower zone, the lower zone parameters were varied during the calibration of JMRA2 while keeping the upper zone values the same as those obtain for MFKA2. Then the lower zone parameter values determined for JMRA2 were used for the MFKA2 lower zone to see whether the initial Middle Fork simulation was significantly changed. A simulation was also run for the small drainage at Slate Creek at Coldfoot for the period with USGS daily flow data (43% of the area is in the lower elevation zone) as a further check on the model parameter values. This simulation was possible because precipitation data were available near the outlet at the Coldfoot SNOTEL site for the period with USGS daily flow records. No simulation was attempted for Wiseman Creek at Wiseman because no precipitation data were available within that small drainage during the period with daily flow records.

In general the parameters for the models seem to produce reasonable results considering the lack of data and possible problems with observed flows due to ice effects and rating uncertainties. However, it should be noted that many of the parameters could be altered over a fairly large range without significantly affecting the overall results. The most important parameters for the Koyukuk Basin are noted in the following sections. The sensitivity of these parameters should be greater than other model parameters.

<u>SNOW-17 Model</u>

Many of the snow model parameters were assigned reasonable values based on the typical climatological conditions for the Koyukuk Basin and were not changed during the calibration. There was too much noise in the records to determine whether these parameters should be altered. The parameters in this category and their assigned values are: NMF=0.20, TIPM=0.10, MBASE=0.0, and PLWHC=0.10. There were also not enough rain-on-snow events at warm temperatures to warrant changing the values for the UADJ parameter though different values were assigned to the upper and lower zones based on the assumption that there would be more wind at the higher elevations during such events (upper zone UADJ=0.15 and lower zone UADJ=0.10). The RSNWELEV operation was used to determine how much precipitation fell as rain versus snow. Area versus elevation information for each of the areas was provided by Scott Lindsey. A PXTEMP value of 1˚C was used to determine the elevation of the rain-snow line. No edits were made to any of the MAT values during the calibration in order to change the form of precipitation even though there certainly appear to be some events that have too much rain or vice-versa. The errors appear to be more or less random and thus shouldn't affect the determination of parameter values.

The primary parameters involved in the calibration for the snow model were SCF, the melt-factors, and the areal depletion curve. It couldn't be determined whether the areal snow cover should remain at 100% for some period after melt begins even during years with the largest amounts of snow, thus the SI parameter value was set to 999.0 which is larger than the amount of water equivalent during any year. This seems logical for the upper zones since there are bound to be areas with shallow cover that go bare when the snow first starts to melt in rugged terrain. It was thought that for the lower zones there might be some drainages that would remain at 100% cover for part of the melt season during large snow years, but this couldn't be determined from the available observed flow data. The melt factors were adjusted during the calibration, but no difference in the values for the upper and lower zones could be determined. Thus, both elevation zones have the same values, MFMAX=0.8 and MFMIN=0.1. The SCF value for MFKA2 was lowered to 0.95 in order to get the proper snowmelt runoff volume during those years that appeared to have the best spring runoff data, while a value of SCF=1.0 was used for JMRA2. For the other areas, the 2 sub-basins above Bettles (North Fork and Bettles local) were arbitrarily assigned the SCF value for MFKA2 and all the sub-basins below Bettles were assigned the value from JMRA2. The areal depletion curves for the upper zones for MFKA2 and JMRA2 were somewhat different. All of the upper zones in the Endicott Mountains (those for KNFA2, BTTA2 local, JONA2, and ALAA2) were assigned the MFKA2 depletion curve. The upper zones in the other sub-basins (SFKA2 and KNRA2), which have less rugged mountains similar to JMRA2, were assigned the Jim River upper zone depletion curve. The lower zone depletion curve, based on the JMRA2 calibration, was used for all the lower zones throughout the basin.

In addition to modeling snow conditions over all the sub-basins and elevation zones, the snow model was also applied to several point locations. These were as follows:

- Bettles Field – daily snow water equivalent (Oct. 80 to current – SNOTEL site with no telemetry), daily snow depth (entire period – NCDC site - assumed not at the exact same location as the SNOTEL measurements), snow course (Oct. 66 to current – values generally around the first of each month)
- Coldfoot – daily snow water equivalent (Jul. 95 to current – SNOTEL site), daily snow depth (Oct. 00 to current – SNOTEL site), daily snow depth (Sep. 93 to Jul. 94 – NCDC site 50-2104), daily snow depth (Oct. 70 to May 77 – NCDC site 50-2103 – Coldfoot Camp)
- Chandlar Lake – daily snow depth (Nov. 68 to Sep. 02 – NCDC site 50-1492)

All the sites used the same values for the minor snow parameters as were used for the areas. The depletion curve wasn't used for the point modeling. UADJ was set to 0.05 for all sites as they were assumed to be reasonably sheltered. Thus, the only parameters that were adjusted were the melt-factors and SCF. SCF values used were: Bettles 1.4, Coldfoot 1.1, and Chandlar Lake 2.0. MFMAX and MFMIN values were: Bettles 0.8/0.2, Coldfoot 0.6/0.1, and Chandlar Lake 1.0/0.2. The comparison of the simulated and observed water equivalents for the Coldfoot SNOTEL site were very good with the maximum simulated water equivalent being within about ±20% of the observed for all years. For the 2 years with daily depth data, the simulated depths were lower than they should have been after differences in simulated and observed water equivalents were taken into account. There are currently no parameters in the snow model to alter the depth computations. At Bettles the simulated water equivalents were generally quite comparable to the observed (both SNOTEL sensor and snow course) except for a few years. Again the simulated snow course depth values were generally lower than they should have been even after water equivalent simulation errors were taken into account. The comparison between simulated depth and the NCDC depth measurements was more erratic. The comparison between simulated and observed depth at Chandlar Lake was reasonable during most years though there were a few years with large differences and some questionable observed data during the most recent years.

SAC-SMA Model

The Koyukuk Basin can be characterized by quick responding storm runoff and significant baseflow that drains fairly rapidly. This indicates that percolation rates must be fairly high, but it doesn't take too much snowmelt or rain to produce fast response runoff (either surface or direct), thus suggesting that the upper zone free water storage should be quite small and interflow not very significant.

The first step when calibrating the Sacramento model was to determine which parameters primarily needed to be adjusted. With the fairly frequent summer rains that begin soon after snowmelt is over and the low ET-Demand rates at these latitudes, large soil moisture deficits were never created. It was also noted that even after the longest dry spells during the record, runoff occurred with very little rain. Based on these observations, UZTWM was set to 10 and LZTWM was set to 50. Since the tension water storages stayed relatively full and with snowmelt or frequent summer rains keeping the lower zone free water storages reasonably full, there was not much variation in the LZDEFR during melt or rain events. This, in addition to the noise in the data, prevented any percolation curve adjustments. Values of ZPERC=150 and REXP=2.0 were used for all areas. With interflow being a relatively minor runoff component and again with the noise in the data, it was difficult to make any adjustments to the UZK parameter. A value of UZK=0.3 was used for all areas. It appeared that there was considerable baseflow recharge even when some soil moisture deficits existed so the value of PFREE was set to 0.8. There was also no clear evidence of constant impervious runoff so PCTIM was set to 0.0. With the small soil moisture deficits there was little chance for riparian evaporation to occur, thus RIVA was set to 0.0. No adjustments were made to the ET-Demand values that were derived for each area. An EFC value of 0.3 was used for all the lower elevation zones and 0.0 for the upper zones which are above the tree line.

The main parameters that were adjusted for the Koyukuk Basin were the lower zone free water storages and withdrawal rates and the size of the upper zone free water storage (determines when surface runoff occurs) and the magnitude of the variable impervious area. For MFKA2 fast response runoff was attempted to be modeled both as surface runoff and as primarily variable impervious runoff with surface runoff only during very large events. The use of variable impervious runoff produced the best results. Just using surface runoff generated too much response from moderate events. Thus, for the upper elevation zones values of UZFWM=25 and ADIMP=0.35 were adopted. As mentioned previously, the Jim River and Slate Creek, which contain more area below 2100 feet, were flashier than the Middle Fork. In order to model the Jim River surface runoff needed to be produced from every reasonably intense event. To do this UZFWM was set to 5 with ADIMP=0.0. These values were used for all the lower elevation zones in the basin.

Significant baseflow levels persist throughout the late spring and summer in the Koyukuk Basin. Once the snow starts to accumulate in the fall the baseflow drops off quite rapidly. Once freeze up occurs there are no gage-height observations thus it is difficult to determine low flow during the winter. The USGS estimates of winter flows generally went to zero for the Middle Fork while some slow draining flow was estimated through the winter for the Jim River during most years. In order to have the high baseflow levels during the summer and the rapid decrease in the early fall, a primary baseflow withdrawal rate of 0.025 was used (LZPK parameter) for all areas. A supplemental withdrawal rate of 0.18 (LZSK parameter) seemed to give the best results. The amount of baseflow seemed to vary with elevation, thus the lower zone free water storage values were different for each zone. For the upper elevation zones LZFSM=20 and LZFPM=60 were used, while for the lower elevation zones LZFSM=10 and LZFPM=40 were specified for all the sub-basins.

The parameter values determined during the calibrations of MFKA2 and JMRA2 produced similar results for Slate Creek. Slate Creek was even somewhat flashier than the Jim River and had slightly higher baseflow levels. To handle this response another parameter set was tried that slightly improved the SLAA2 results. This set used UZFWM=15 and ADIMP=0 for both elevation zones thus generating somewhat more surface runoff overall. The LZSK value was changed to 0.12 and LZFSM=15 and LZFPM=50 were used for both elevation zones. These parameters were tried on JMRA2 and MFKA2, but the results were judged to be worse, thus they were not applied to any other area.

Unit Hydrographs

The initial calibration of MFKA2, JMRA2, and SLAA2 used only mean daily flow data as the peak flow data obtain via the USGS web site didn't work in the PEAKFLOW operation. Thus, the initial unit hydrographs were based only on mean daily flows. In order to determine reasonable unit hydrographs for the other sub-basins, it seemed like having synthetic unit graphs for all the areas would be helpful. Scott Lindsey derived synthetic unit hydrographs for most areas using IHABBS (there was some problem with the elevation data for the Kanuti sub-basin that the tool couldn't handle, thus no synthetic unit hydrograph was derived for that drainage). Scott used the Classic Time/Area method. These GIS based unit hydrographs peaked more rapidly than the calibration unit hydrographs developed using mean daily flow data. A simple routing procedure was applied to the GIS based unit graphs for the 3 calibrated watersheds to produce a close approximation to the unit graphs derived using only the mean daily flow data. These routing parameters were then applied to the GIS unit graphs for the other sub-basins to determine unit hydrographs for these drainages that were consistent with those for the calibrated watersheds. The initial simulations for Hughes were generated using these unit hydrographs.

Later it was found that by editing the USGS peak flow tables that the PEAKFLOW operation could be made to work. When this was done, it was clear that the simulated peaks for the 3 calibrated headwaters were too low. Using the GIS based unit hydrographs improved the peak flow simulation and only slightly deteriorated the daily flow statistics. Thus, it was decided to adopt the GIS based unit hydrographs for all sub-basins. Since the GIS unit hydrographs were for the entire drainage area of each sub-basin, subjective adjustments were applied to get separate unit hydrographs for each elevation zone. For the Kanuti watershed the GIS unit hydrograph for the South Fork, adjusted for differences in drainage areas, was used.

Channel Routing

The Lag and K routing procedure was used for the local areas within the Koyukuk Basin, i.e. Bettles, Allakaket, and Hughes. The approach that was used was to lag each of the headwater flows to the downstream point, combine them with the unit hydrograph generate flows for the local area, and then apply a variable lag and constant or variable attenuation. The only deviation was for the Allakaket local where the Alatna River was treated separately from the combination of the upstream flows (Bettles, John, and South Fork) and the local area flows before producing the total flow at the point. Constant lag and constant K values were initially subjectively estimated and then modified based the comparisons of simulated and observed flows at each point. Constant lag and K values appeared sufficient for most events, however, it was clear that additional lag or attenuation were needed in order to properly model the 1994 flood when the river went considerably over bank. Bettles and Hughes use a variable lag and K at higher flow levels. Allakaket uses only a variable lag with K constant for all flow levels. While the variable routing parameters are primarily based on the 1994 flood they do have some affect on a few other events, however, it would be better to have additional very large events in order to have more confidence in the high flow routing parameters.

Adjusted instantaneous flows (QINE time series) were generated at the sites with mean daily flow data (ADJUST-Q operation modifies the simulated instantaneous flows to closely match the observed daily volumes). The QINE time series were produced for inclusion on instantaneous flow displays (using the PLOT-TS operation). Because of uncertainties in the observed daily flows due to ice effects and periods with no gage-heights, the QINE time series were not routed downstream. The computed flows at the mainstem locations are thus based totally on simulated results.

Simulation Results

The simulation results will be discussed for each flow point with observed data separately and then all the points will be examined together. When looking at the results for all the points simultaneously, problems with observed flow data are more apparent as one can see inconsistencies between the measurements from one point to another that can't be explained by realistic differences in rainfall, snowmelt, or runoff patterns. The 1994 flood will be discussed separately as it is clearly the most important event during the calibration period. In addition, differences in the flow simulations using the different temperature networks will be described. While some figures and statistics are provided in this report, in order to follow the discussion and properly evaluate the conclusions the ICP program must be run using the data on the CD and the WY-PLOT and PLOT-TS displays examined.

Middle Fork of the Koyukuk near Wiseman

In general the snowmelt runoff periods for the Middle Fork are simulated quite well. This includes the period with USGS mean daily flows (water years 1973-78 and 1983-87 – water years 1971 and 1972 were not included in the calibration as noted previously) and the period with manual daily stage measurements (water years 1999-2002). During some of the earlier years there are some problems near the beginning of the snowmelt runoff period (water years 74, 76, 78, 84, and 87) that could very well be caused by estimated USGS flow volumes during periods with no gage-heights. During the later years when manual stage readings were being used, there are stage values recorded for a week or two prior to when snowmelt runoff begins that convert to fairly high flows. Exactly what is being measured is not clear, but once simulated runoff begins, the comparison between simulated and observed flows is very good to excellent for the rest of the melt season.

The comparison of simulated and observed flows during the summer is much more erratic. There are times when large flows are simulated and very little runoff observed and times when there is a significant observed peak and little simulated flow. This is most likely the result of the convective nature of most summer storms and the general lack of precipitation data within the watershed. During the early years the only stations near the Middle Fork watershed were Coldfoot Camp to the south, Chandlar Lake to the east, Galbraith across the Brooks Range divide to the north, and Wild Lake 2 far to the west. In the later years there is a station at the outlet (Wiseman) and at the northern edge of the watershed (Antigun Pass) but none within the drainage.

Table 4 shows the overall calibration statistics for the Middle Fork and the other locations with mean daily flow records. The overall bias of just over 8% is primarily due to simulated flows being greater than estimated observed values at the beginning of the melt season during a number of years. Parameters were adjusted so as to have a reasonable volume during the years without the early melt season problems and overall during the summer months. There is a tendency to under simulate high flows and over simulate low flows as is typical when applying a lump model, especially in areas with significant snowmelt runoff (reflected in the slope of the best fit line). This tendency is magnified in the statistics due to the summer storm problems since the flow intervals are based on observed conditions. The ratio of simulated to observed peaks is also somewhat misleading. In reality when the simulated mean daily peak flow is close to the observed, the instantaneous peak flow is also close to the observed and when the simulated mean daily is high or low, the simulated instantaneous peak is high or low by about the same relative amount. Since, in general, mean daily high flows are under simulated; the overall instantaneous peak flow ratio is less than 1.0. It would be better if the PEAKFLOW operation looked at the ratio of simulated to observed flows for both mean daily and instantaneous values. The fact that the simulated to observed ratios are about the same for instantaneous flows and daily volumes on peak days indicates that the shape of the simulated hydrographs are quite realistic.

The only rating curve available for the Middle Fork was the one used by the USGS when records were discontinued in 1987. Scott Lindsey had gotten some information that the rating was shifting and also that the 1994 flood event deposited considerable bedload at the bridge where the stage readings are made. A new rating was developed by plotting simulated flows versus observed stages. This assumes that the simulated flows, in general, are reasonable and unbiased. Figures 5a and 5b show plots of flow versus stage for the Middle Fork. These figures include simulated instantaneous flows plotted against observed stages based on data from July 1998 to June 2002 (high stages prior to the beginning of snowmelt runoff were neglected – also summer 2002 stages were not included as they appeared out of line with the other data). The figures also show the 1987 rating curve and the revised rating based on the data points. In addition, the plots include observed instantaneous peak flows and stages as reported by the USGS (these were for water years 1987 or earlier except for the highest value which was an estimate for the 1994 flood).

Jim River near Bettles

The results for the Jim River were basically similar to those for the Middle Fork though there was a little more scatter. The snowmelt runoff periods were generally quite reasonable except for a significant over simulation of volume in 1974 and the computation of a rise due to melt and rain prior to any observed runoff in 1976. The summer periods were again quite erratic with very large over simulations in June 1974 and July 1977 and quite large under simulations in August 1972 and September 1975. As far as volume, as with the Middle Fork, the aim was to get a reasonable volume during the majority of snowmelt runoff periods and overall for most of the summer storms. Although the average simulated to observed peak flow ratio was lower than for the Middle Fork, the ratio of simulated to observed peaks were very similar to the ratio of simulated to observed mean daily volumes on the days when the peaks occurred. Summary statistics are in Table 4.

Slate Creek at Coldfoot

The summary statistics for Slate Creek as shown in Table 4 are a little better than those for the Middle Fork and the Jim River. Snow runoff is simulated quite well except for the rise at the beginning of the 1997 melt season. Rain events are more erratic though there is not as much scatter as for the other 2 watersheds. Perhaps this is due to having precipitation measurements at the watershed outlet given the size of the drainage. The ratio of simulated to observed instantaneous peaks is closer to 1.0 than for the other 2 watersheds. This is due to the ratio of simulated to observed mean daily flows being closer to 1.0. Most of the high peaks for Slate Creek are the result of heavy convective storms over the watershed and do not show up as large events at downstream points. Such events can cause washouts along the Dalton Highway even though they don't cause any widespread flooding.

Koyukuk River at Bettles

Manual readings of stage from a slope gage on the bank are available for open water periods for most years beginning in June 1970. As reported by Scott Lindsey, channel cross-section measurements were taken in 1993 and a rating curve established (Scott didn't provide any streamflow measurement made at that time). Based on later cross-sections and photographs (see Bettles_rating_and_survey_info.xls file) it was apparent that the left bank (looking upstream) eroded significantly. In the fall of 2003 the measurement site was moved several hundred feet upstream of the old site (according to Scott the new site isn't idea, but it's better than the old site). A flow measurement was made in 2004 and a rating curve generated, however, this rating only applies to data beginning in September 2003.

Figures 6a and 6b show the comparison of simulated flows and observed stages at Bettles. Using the 1993 rating curve there was a tendency for "observed" low flows to be greater than simulated values and "observed" high flows to be lower. A new rating curve was fitted to the data so that it minimized this tendency and was used to make the flow comparisons. The fitted rating is shown along with the 1993 rating curve in Figures 6a and 6b. This fitted rating curve assumes that the simulated flows are reasonable and unbiased.

While still exhibiting more scatter than at the Middle Fork stage site upstream (see Figures 5a and 5b), the comparison of simulated and "observed" flows at Bettles is better starting in 1978 (except for "observed" flows being considerably low in the spring of 1988 and being very high during the early part of the melt season in 1996). Prior to 1978 the "observed" values appear to be way too low some years and way too high during others indicating that there may be a problem with the rating curve or the stage measurements themselves. Figures 6a and 6b only include the data beginning in water year 1978. The routing parameters (variable lag and attenuation) used at Bettles were based more on the timing of the rises based on "observed" flows than on the magnitude derived from the rating curve.

The amount of scatter between simulated and "observed" flows at Bettles is definitely greater during the snowmelt runoff season than at the headwater gages, both in terms of volume and peaks. Part of this may be caused by the fact that there are no precipitation gages within the North Fork drainage which is a major contributor at Bettles and some of the discrepancy may be due to rating and stage measurement issues. During the summer the scatter at Bettles appears to be somewhat less than for the headwater locations. This is probably due to the diminishing affect of more localized convective storms as the size of the drainage increases.

Koyukuk River at Allakaket

Manual readings of stage using a slope gage also began at Allakaket in 1970. These data are available for the open water season during most years since then though there are gaps from 1984 to June 1989 and for several years after the 1994 flood caused the village to be relocated (gap from September 1994 to 1998 except for a few summer readings). A flow measurement was taken in 1993 and a rating curve established. A flow measurement was made again in 2004 and a new rating constructed. The 1994 flood event caused some changes in the channel cross-section as can be seen in the file Allakaket_survey_and_rating_info.xls. For the calibration, the 1993 rating was originally used except that the upper end of the rating was modified to include the stage based on the high water mark and the USGS estimated peak flow for the 1994 flood. Based on a comparison of the simulated flows to measured stages as shown in Figures 7a and 7b a few revisions were made to that rating curve between stages of 14 and 26 feet. This "1993 Modified" rating curve was used for the comparison during this study.

In general, the comparison of simulated and "observed" flows at Allakaket indicates fairly good results. The amount of scatter is similar to that at Bettles. Some of the errors are undoubtedly simulation errors though some of the scatter is likely caused by rating variations over time and bad stage data. The discrepancies between simulated and "observed" conditions are similar at this downstream location during the summer months as they are during the snowmelt runoff season. The erratic behavior during the summer exhibited at upstream points as a result of small scale convective storms is washed out by the time one gets this far downstream. Only more general summer rain events cause a significant rise at Allakaket. The only major summer event during the period of record is the 1994 flood.

<u>Koyukuk River at Hughes</u>

The Koyukuk River at Hughes has USGS streamflow records through water year 1982. The most significant events during that period were produced by snowmelt runoff. There were no large runoff events during the summer period. The greatest snowmelt peaks occurred in the 1960s with the largest occurring in 1963, 1964, and 1968. There are clearly bad observed daily flow values in 1963. In 1964 the simulated shape of the snowmelt runoff period is good though the peak is somewhat low. In 1968 the simulated peak is low by an even greater amount. It is fairly common when using a temperature index snow model, for the largest snowmelt events to be under simulated. This is because the greatest snowmelt typically occurs when abnormal meteorological conditions produce above normal melt rates. It should also be noted that the precipitation and temperature networks were minimal during the 1960s with almost all data at lower elevations along the rivers.

Most summer events are simulated in a reasonable manner though there are several events that are missed badly, most notably August 1973. However, as mention previously there are no large summer events during the period of record. The summary statistics for Hughes, as shown in Table 4, are slightly better than for the other locations with USGS streamflow data. This is primarily due to less erratic behavior in the summer due to convective activity not having much effect for the large drainage area. The spring snowmelt periods are not simulated as well at Hughes as for the headwater locations. This is perhaps due to large contributing watersheds, North Fork, John, Alatna, and Kanuti, with very little data during the period of record at Hughes. Again for Hughes, as for the headwaters, the ratio of simulated to observed peaks is similar to the ratio of computed to observed mean daily flows on the days when the peaks occurred.

<u>All Locations with Observed River Data</u>

The MCP deck for Hughes includes a PLOT-TS operation that summaries the simulations at all locations with observed river data that were used in the simulation of flows for the Koyukuk Basin (SLAA2 is not included). The "observed" flows on this display are

QINE time series for those points with mean daily flows (MFKA2, JMRA2, and KRHA2) and QIN time series for those points with stage measurements (BTTA2 and ALLA2). The QINE time series for MFKA2 is generated using mean daily flows for the period with USGS data and "observed" instantaneous flows during the later years when stage measurements were available. During periods when there are observations at multiple points this PLOT-TS display makes it fairly easy to pick out questionable "observed" flows. For example, in the spring of 1971 the observed flows for the Middle Fork clearly appear to be in error as all the other locations show observed runoff several weeks before the MFKA2 hydrograph responds. The spring of 1973 illustrates a case where the observed streamflow data at Hughes appears to be in error. All four of the other locations respond well before the USGS values at Hughes show any increase. A similar situation seems to occur in 1979 though the only other locations with observations are Bettles and Allakaket.

August 1994 Flood

Table 5 shows the precipitation reports that were available for the flood. The value for Antigun Pass for the second storm, as mentioned previously, is based on an assumed accumulated total. The NRCS total for the period from 8/24 to 9/16 was 5.7 inches. Based on the average ratio of ATGA2 to TOOA2 for that time of year of about 2:1 and a TOOA2 9/1 to 9/16 total of 0.9 inches, the second storm rainfall for ATGA2 was estimated as 3.9 inches (5.7 – 2*(0.9)). The storm totals for Coldfoot were obtained from the 1994 flood report (Meyer and Lindsey, 1995). Data records for Coldfoot couldn't be located by the APRFC during this study (NCDC shows missing data for August 1994). The values for the RAWS sites were based on the data files supplied by the APRFC and differ somewhat from those in the flood report. The values for Bettles are based on the NCDC records and also differ somewhat from those given in the flood report.

Table 6 shows the simulated peaks for the event and the available observations of observed stages and estimated flows. The simulated and estimated peak flows at Allakaket and Hughes are very close. As noted previously, the high flow routing parameters are based almost entirely on this event as there were no other events of this magnitude. The second largest event was the snowmelt runoff period in late May 1993. There was no stage or estimated flow values at Hughes for that event (simulated peak of 245,000 cfs). There were stage values at Bettles for most of the event and at Allakaket for the initial portion of the rise, but these didn't have a major impact on the routing model parameters.

The simulated flow for the first storm is greater for the Jim River than for the second storm. For the Jim River the rainfall for the first storm was slightly greater than during the second storm and the intensities were higher. Initially the accumulated precipitation totals for both storms at Coldfoot and the second storm at Antigun Pass were not included. This resulted in much lower peaks for the drainages in the northeast portion of the basin. When these accumulated totals were included the peaks increased dramatically. At that point in the study the simulated peaks for the first storm were much higher than currently at a number of the flow points. For example, at the Middle Fork gage the peak for the first storm was even greater than the peak for the second storm. This was caused by Fairbanks being the only hourly station with data. Since the small amount of precipitation during that storm at Fairbanks occurred in a short time, the MAP values for the Middle Fork had all the precipitation lumped into two 6 hour periods. These high intensities produced large amounts of surface runoff. At that point it was decided to obtain the hourly data for the RAWS sites so that a better estimation of rainfall intensity could be obtained. The inclusion of the RAWS hourly data changed the timing and magnitude of the simulated peaks for quite a few events during the period that these data were available.

The calibration results at Bettles produce simulated peaks for both storms that are similar to those obtained from the observed stages and the fitted rating curve, however, the stage data indicated that the flows stayed higher between peaks than what was simulated. At Allakaket the simulated peak for the first storm was higher than that derived from the stage data, but the remainder of the sequence showed close agreement between simulated and "observed" flows. No data were available for the recession at Allakaket since the gage was wiped out when the village was destroyed. The stage data at Bettles showed a sharp drop after the peak for the second storm. The simulated flows at Bettles, Allakaket, and Hughes all exhibit a sharp drop after the second peak.

Effect of Different Temperature Networks

Three sets of MAT time series were generated for each area. The set used for calibration was based on station, Reanalysis, and radiosonde data; i.e. all available temperature data (referred to as 'all'). The other two sets were generated for comparison purposes. One of those sets uses only data from ground stations (referred to as 'gages'). The other uses data from Reanalysis locations (referred to as 'reanal'). The same synthetic stations with the same mean monthly max and min temperatures were used in all cases.

Table 7 shows summary statistics from each set of MAT time series for the Middle Fork, Jim River, and the Koyukuk at Hughes. For the Middle Fork the statistics are quite similar for all cases, though just using the Reanalysis data produces a slightly higher daily RMS/$\overline{Q}$ ratio and slightly lower values for the correlation coefficient and sim/obs peak ratio. For the Jim River the Reanalysis data generates the worse results. Just using the station data produces a very slight improvement over using all available temperature data. For Hughes the results are similar to those for the Jim River with the station data generating the best overall statistics, followed by using all the data and then only using the Reanalysis temperatures.

When comparing hydrographs generated with each set of MAT time series at the 5 main locations with observed river data (MFKA2, JMRA2, BTTA2, ALLA2, and KRHA2), the conclusions were:

- The main difference between hydrographs produced with each set of MAT time series is in the timing of the snowmelt runoff. Differences also resulted from the precipitation being allocated differently between rain and snow for some events, primarily during the transition periods from winter to summer and summer to winter.

- For the Middle Fork the differences in snowmelt timing when comparing 'gage' to 'all' time series occurred mostly in the 1960's and 1980's. These are the periods when the station temperature network was less dense and more weight was thus put on the Reanalysis data. The 60's had greater differences than the 80's (less station temperature data were available in the 60's than at any other time). When comparing 'reanal' to 'all' time series, the opposite was true, i.e. the differences primarily occurred in the 70's and 90's when the station network was densest and thus had more weight.

- When comparing the 'gage' to the 'reanal' time series generated hydrographs at all 5 sites, there were differences during most years in the timing of the snowmelt runoff. Overall the 'reanal' time series produced melt sooner than the 'gage' time series for just over half the years, while the 'gage' time series only started generating melt earlier during 15% of the years. During the other years the response was similar for both sets of time series. It was also noted that this effect was not as great at the Middle Fork as at the downstream locations. From the beginning of the record through the mid 80's the 'reanal' time series produced melt earlier than the 'gage' time series about 2/3rds of the time, while in the later years there was no real trend. The reason for this is unknown.

The overall judgment is that the Reanalysis data could be used to calibrate and operationally apply a snow model when there is a lack of station data, however, better results can be obtained when temperature data are available from ground sites, especially at a range of elevations. A minimal amount of station data is a common occurrence in many parts of Alaska. There could be differences in temperature versus elevation relationships derived from station data as compared to lapse rates and inversion levels indicated by the Reanalysis data. Summer lapse rates were similar for the Koyukuk, but during other seasons the lapse rates derived from the station data were steeper. Also the Reanalysis data indicated that an inversion persisted for a longer time than indicated by the station or radiosonde data.

Summary

The overall results from the calibration of the Koyukuk Basin are judged to be quite good considering the sparseness of the precipitation network, the lack of observed streamflow data, and the fact the model parameters were based on calibrations over less than 10% of the drainage area. It was very beneficial to obtain additional hourly precipitation data for summer periods during the later years. This significantly improved the estimate of rainfall intensity which is very important in an area like the Koyukuk where surface runoff occurs frequently and is needed to simulate the rapid response of the rivers. There is considerable uncertainty in the values of many of the snow and soil moisture model parameter values due to the noise in the data and the fact that certain situations seldom, if ever, occur during the period of record. Reasonable values were subjectively assigned to many of the parameters based on climatic and physiographic factors. The emphasis during the calibration of these models was on those parameters which primarily controlled the timing and volume of snowmelt and the timing and type of runoff. GIS based synthetic unit hydrographs which indicated that the water moves quickly through the channel system provided realistic shaped hydrographs based on comparisons of simulated to observed peak flow ratios to simulated to observed mean daily flow ratios on the days when the peaks occurred. High flow routing parameters are based almost entirely on the August 1994 flood. The overall simulation results for this devastating flood were very good with simulated peaks in good agreement with USGS estimates at the Middle Fork, Allakaket, and Hughes gage sites. Temperature data from the NCEP/NCAR Reanalysis Project could be used to apply a snow model, but improved results can be obtained when ground observations, especially at various elevations, are available.

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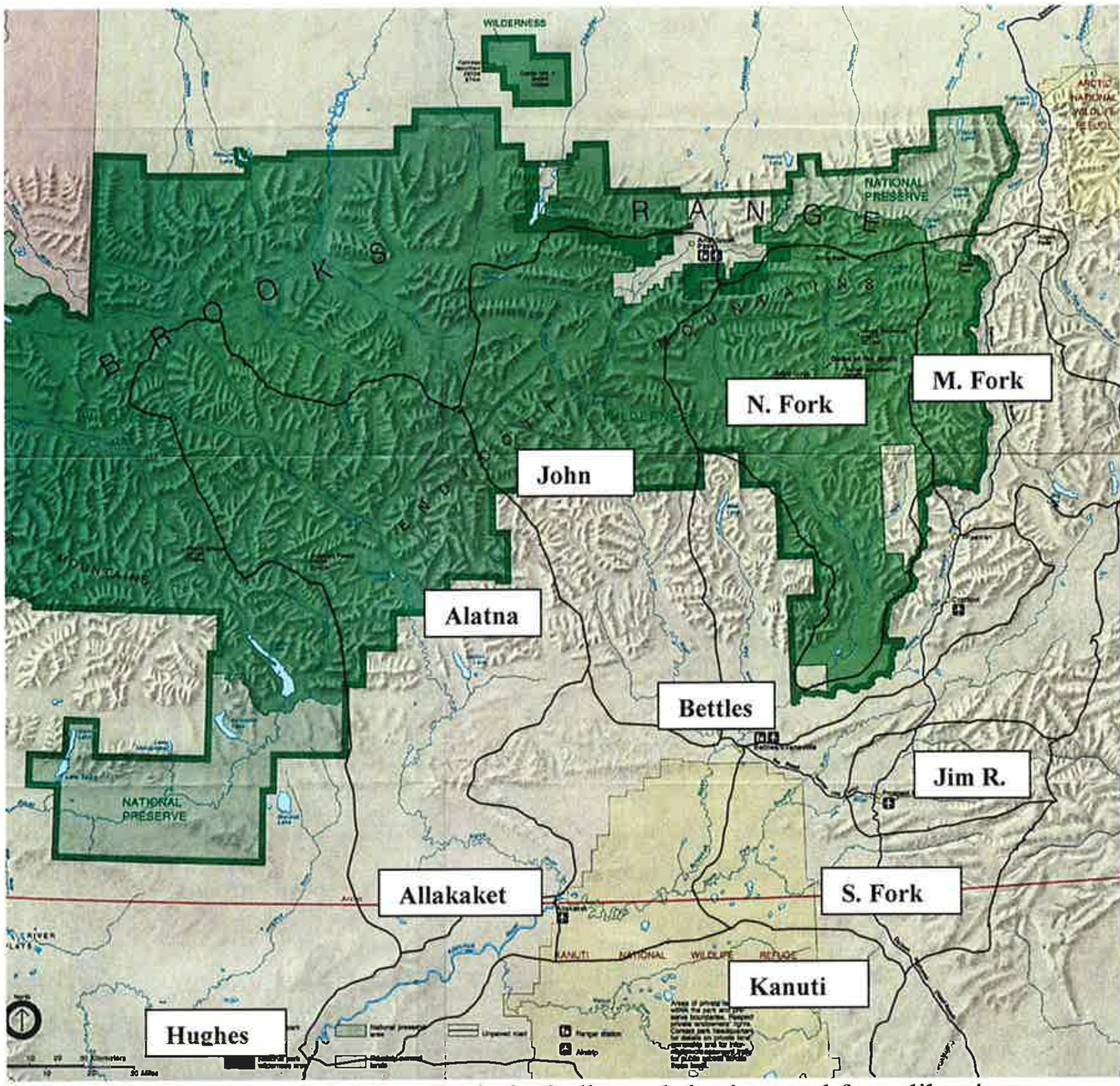

Figure 1. Koyukuk River Basin including sub-basins used for calibration.

Name	Identifier	Area (sq. mi.)	% in Lower Zone
Middle Fork nr Wiseman	MFKA2	1200.	15
North Fork	KNFA2	1861.	26
Koyukuk at Bettles	BTTA2	1169. (local)	57
John River	JONA2	2772.	28
Jim River nr Bettles	JMRA2	465.	59
South Fork	SFKA2	1876. (local)	74
Alatna River	ALAA2	3580.	50
Koyukuk at Allakaket	ALLA2	1163. (local)	100
Kanuti River	KNRA2	3418.	89
Koyukuk at Hughes	KRHA2	1197. (local)	100

Table 1. Koyukuk Basin sub-basins.

Station	ID	Elev (ft)	Latitude	Longitude	Start Data	End Data
Allakaket	ALLA2	400	66.57	-152.65	Jan-53	Oct-82
Allakaket 40 SSW hrly	KANA2	825	66.09	-152.17	Apr-92	
Allakaket 40 SSW dly	KANA2	825	66.09	-152.17	Jul-91	
Ambler West	50-0260	120	67.08	-157.87	Dec-81	Mar-92
Anaktuvuk Auto	50-0270	2100	68.17	-151.77	Jul-53	Aug-73
Antigun Pass	ATGA2	4800	68.13	-149.48	Feb-82	
Bettles	PABT	642	66.92	-151.52	Oct-51	
Chandalar Lake	PALR	1895	67.52	-148.5	Nov-68	Jul-03
Coldfoot	CDXA2	1050	67.25	-150.18	Sep-93	Sep-99
Coldfoot Snotel	COFA2	1040	67.25	-150.18	Jul-95	
Coldfoot Camp	50-2103	1102	67.27	-150.23	Oct-70	May-77
Fairbanks hrly	FAI	432	64.8	-147.88	Oct-62	
Fairbanks dly	FAI	432	64.8	-147.88	Oct-51	
Five Mile	50-3082	502	65.93	-149.83	Sep-70	Aug-80
Galbraith	50-3210	2667	68.48	-149.48	Oct-70	Aug-80
Gobblers Knob	GOBA2	2030	66.75	-150.67	Jul-97	
Hodzana River hrly	HOZA2	1075	66.74	-148.68	Mar-92	
Hodzana River dly	HOZA2	1075	66.74	-148.68	Jul-91	
Hog River hrly	HOGA2	685	66.18	-155.67	Jun-86	
Hog River dly	HOGA2	685	66.18	-155.67	Jun-85	
Hughes	KRHA2	545	66.07	-154.23	Oct-51	Jan-70
Huslia 50 NW	KOYA2	300	66.01	-157.57	Jun-94	
Huslia 50 NW	KOYA2	300	66.01	-157.57	Jul-91	
Imnaviat Creek	TOOA2	3050	68.62	-149.3	Jun-81	
Indian Mtn	PAIM	1220	65.98	-153.68	Aug-66	Jan-85
Keystone Ridge	50-4621	1600	64.92	-148.27	Jul-97	
Kobuk	50-4964	140	66.9	-156.87	Aug-53	Dec-79
Mile 42 Steese	50-5880	1000	65.22	-147.17	Jun-00	
Norutak Lake hrly	NRUA2	800	66.85	-154.34	Jun-89	
Norutak Lake dly	NRUA2	800	66.85	-154.34	Jun-89	
Prospect Creek	50-7778	955	66.82	-150.67	Oct-70	Aug-80
Rampart 2	50-7900	400	65.5	-150.13	Jun-63	May-70
Tanana AP	50-9014	227	65.17	-152.1	Oct-51	
Wild Lake 2	50-9859	1191	67.55	-151.55	Dec-63	Aug-72
Wiseman	50-9869	1147	67.42	-150.1	Aug-96	

Table 2. Precipitation Stations for the Koyukuk Basin.

Station	PRISM averages (inches) Winter	Summer	PXPP/PRISM Winter	Summer	PXPP 63-02/PXPP 61-90 Winter	Summer
Allakaket	5.02	7.84	1.25	0.95	0.98	1.01
Ambler West	8.94	13.99	1.14	0.82	1	1.08
Antigun Pass	10.53	16.5	0.79	0.95	0.9	1.06
Bettles	6.14	8.64	0.92	0.94	1.01	1.06
Chandalar Lake	4.06	7.28	0.81	0.86	0.95	0.99
Coldfoot Camp	7.58	10.37	0.91	1.21	1.02	1.06
Fairbanks hrly	4.3	7.17	0.93	0.92	0.95	0.97
Fairbanks dly	4.3	7.17	0.93	0.95	1	0.97
Five Mile	4.08	5.69	1.04	1.06	1.01	1.04
Galbraith	4.15	8.37	0.97	0.7	1.06	1.05
Hughes	5.13	7.26	1.09	1.04	0.84	1
Imnaviat Creek	4.4	8.73	0.88	0.94	0.91	1.16
Indian Mtn	9.09	10.61	1.02	0.94	0.98	1.06
Kobuk	4.85	12.27	0.93	1.22	0.98	1.04
Prospect Creek	5.7	11.82	0.93	0.89	1.02	1.05
Rampart 2	4.25	6.21	1.02	1.11	1	1.04
Tanana AP	4.6	8.41	0.99	0.98	0.95	0.99
Wild Lake 2	3.64	6.34	0.78	1.07	1.02	1.06
		Average	0.96	0.98	0.98	1.04

Table 3. PRISM and PXPP average seasonal precipitation for WY 61-90.

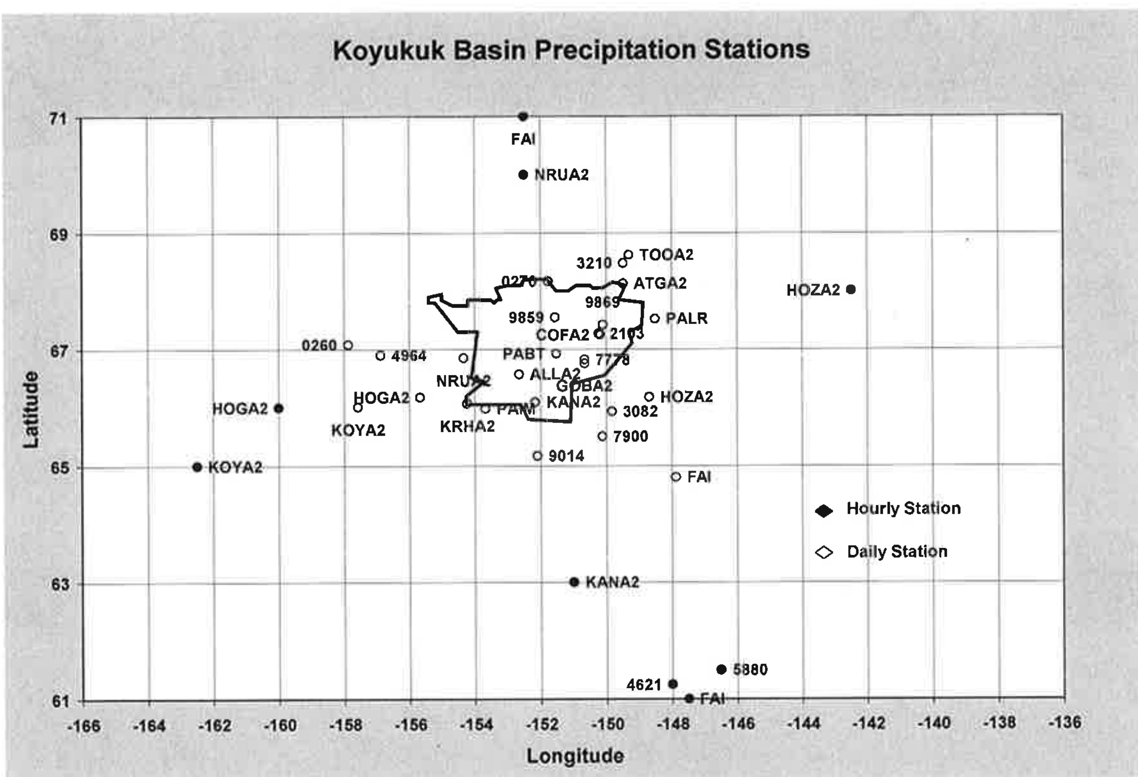

Figure 2. Location of Stations for computing MAP time series.

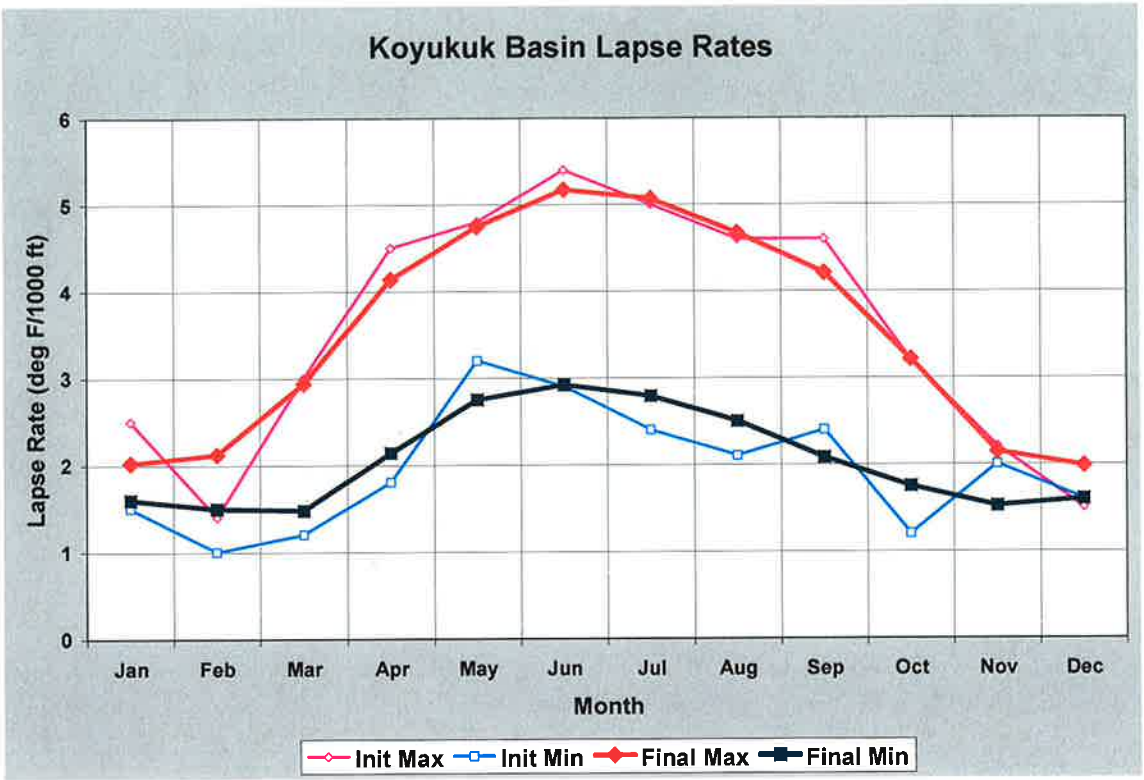

Figure 3. Lapse rates for the Koyukuk Basin.

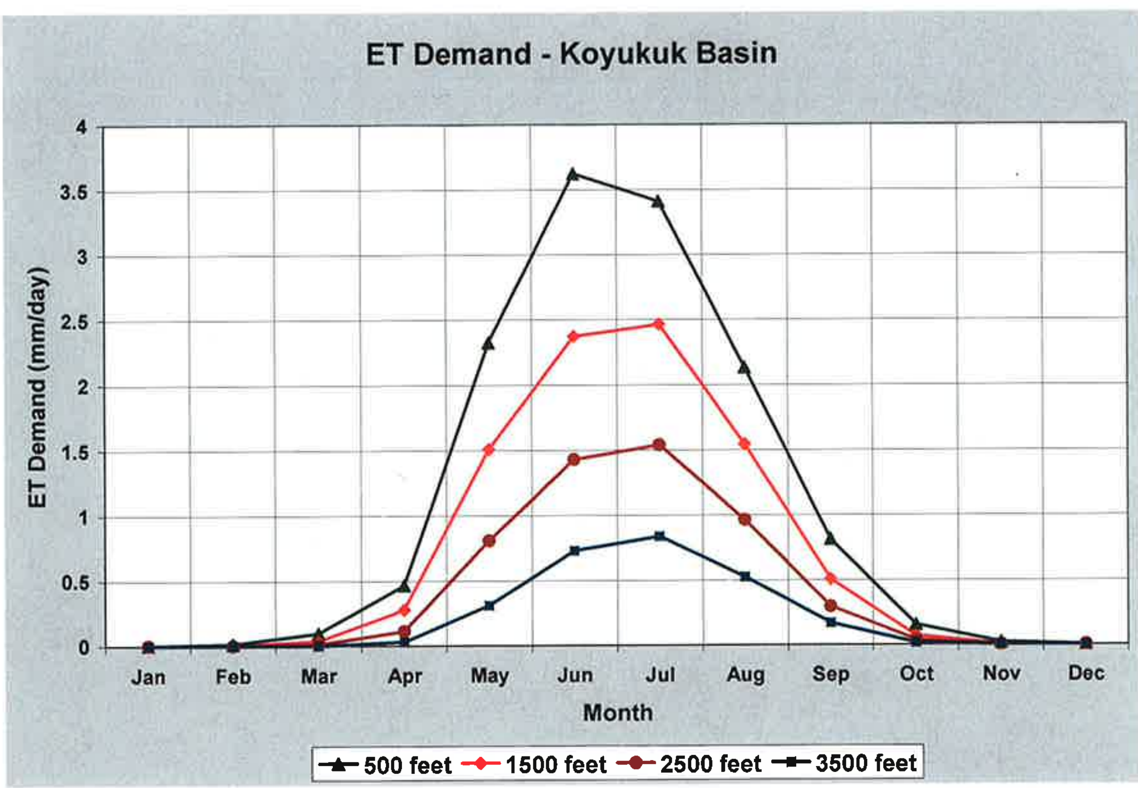

Figure 4. ET-Demand curves for various elevations for the Koyukuk Basin.

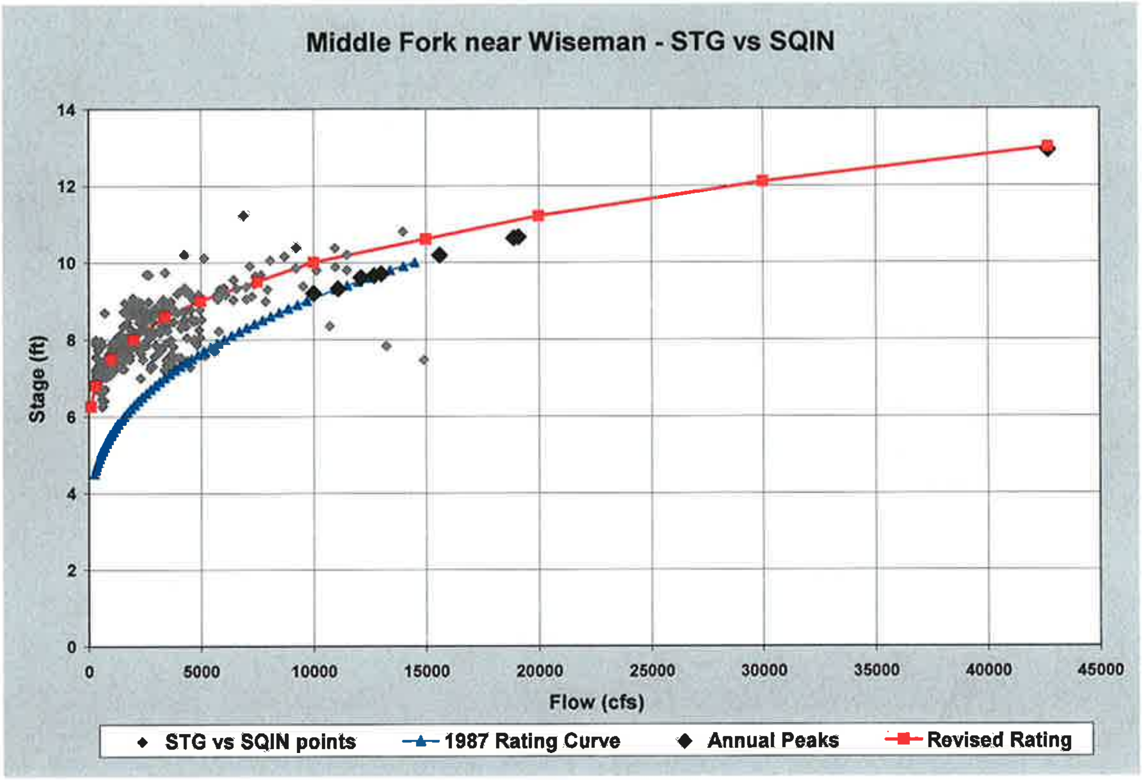

Figure 5a. Middle Fork rating curves, peaks, and simulated flow versus observed stage measurements – arithmetic scale.

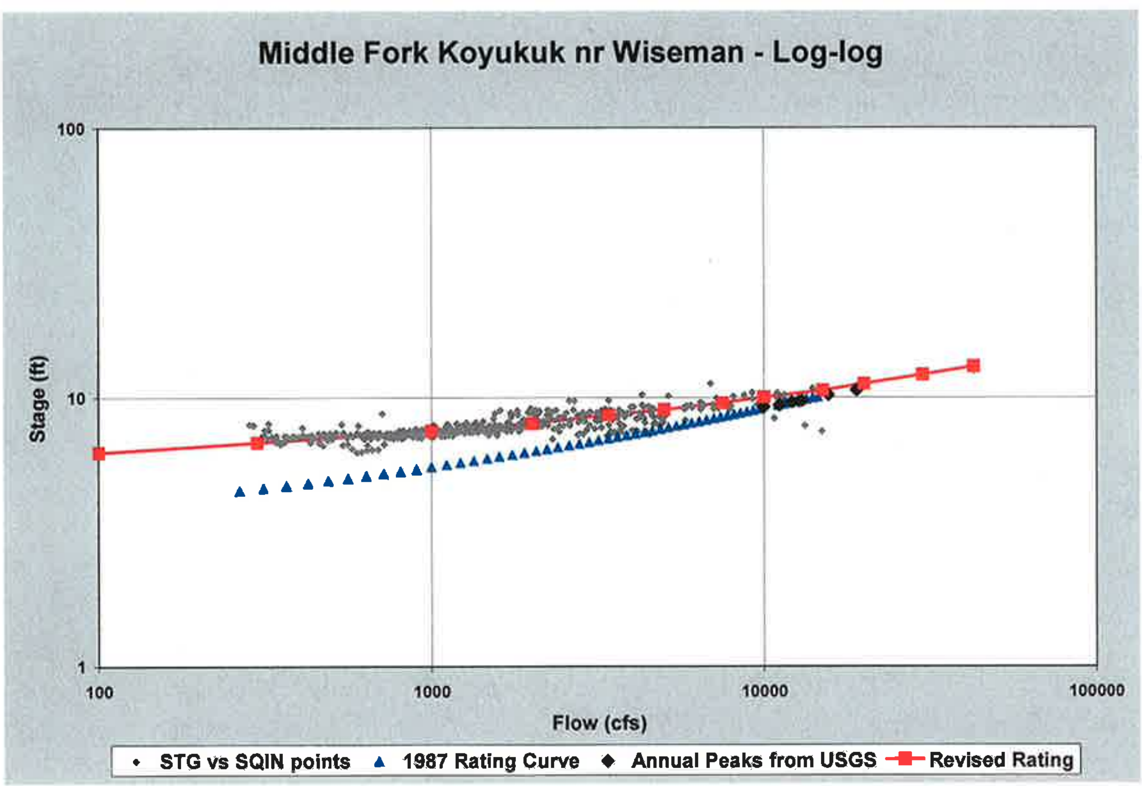

Figure 5b. Middle Fork at Wiseman stage versus flow – log-log scale.

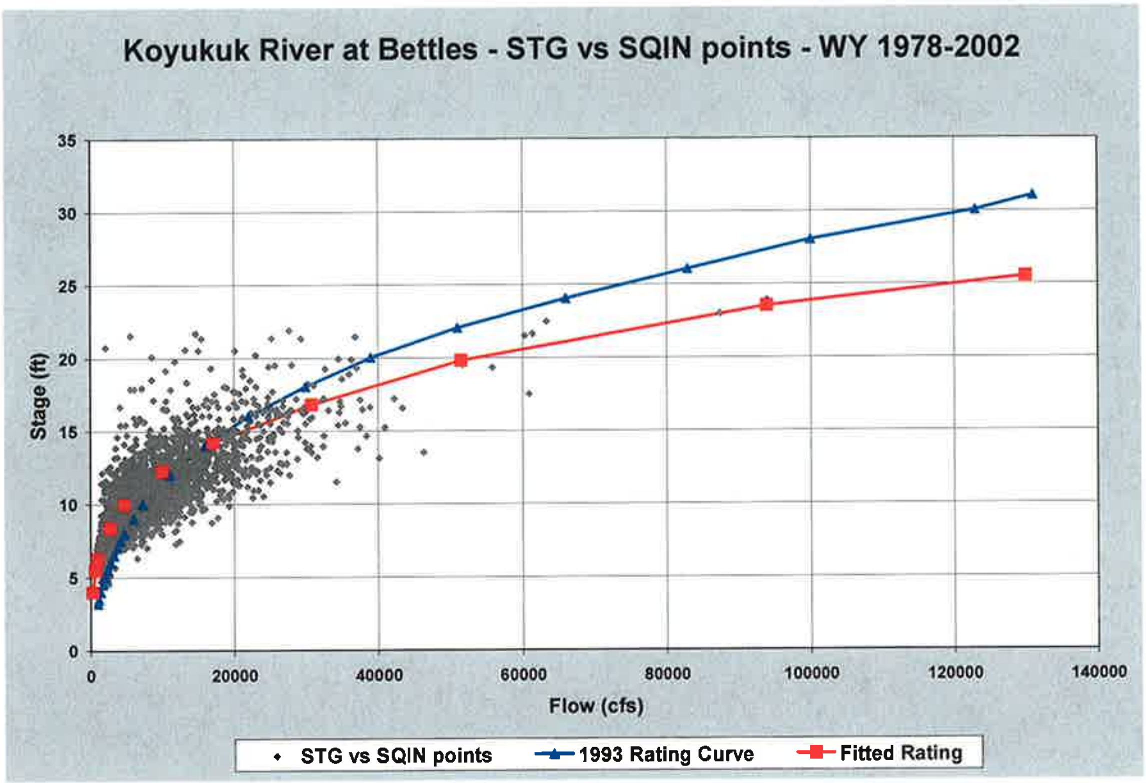

Figure 6a. Koyukuk at Bettles rating curves and simulated flow versus observed stage measurements – arithmetic scale.

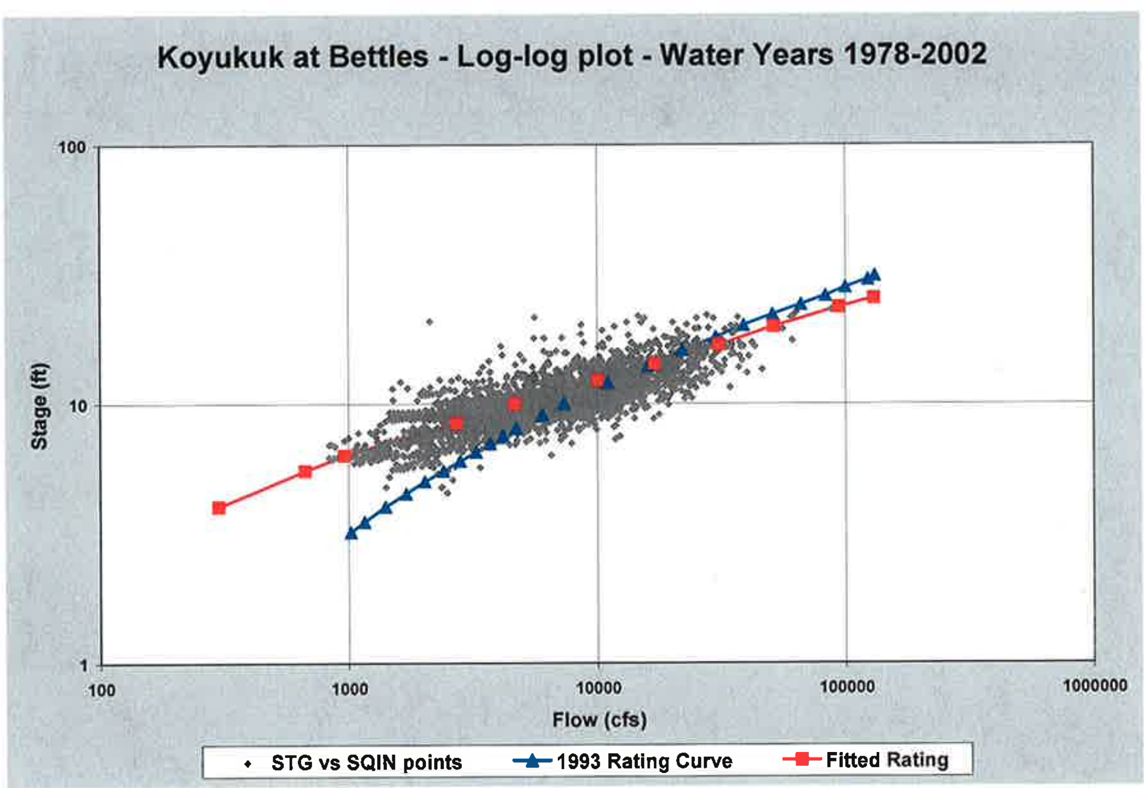

Figure 6b. Koyukuk at Bettles stage versus flow – log-log scale.

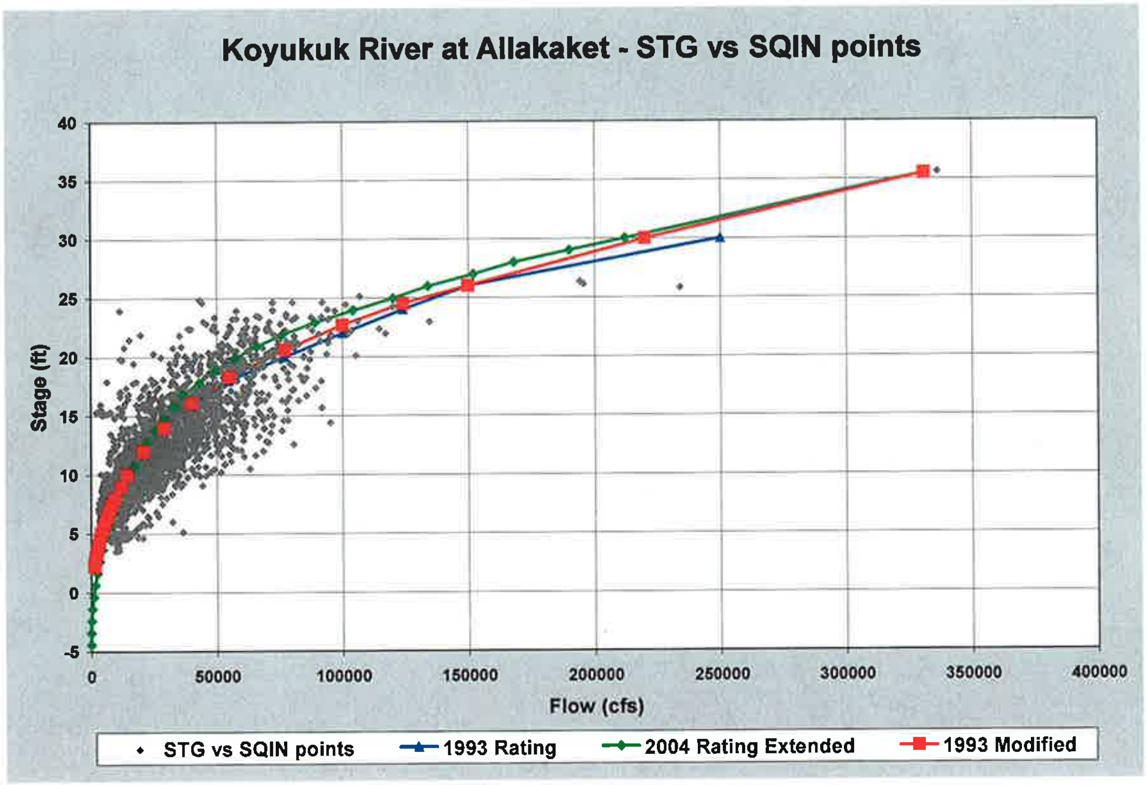

Figure 7a. Koyukuk at Allakaket rating curves and simulated flow versus observed stage measurements – arithmetic scale.

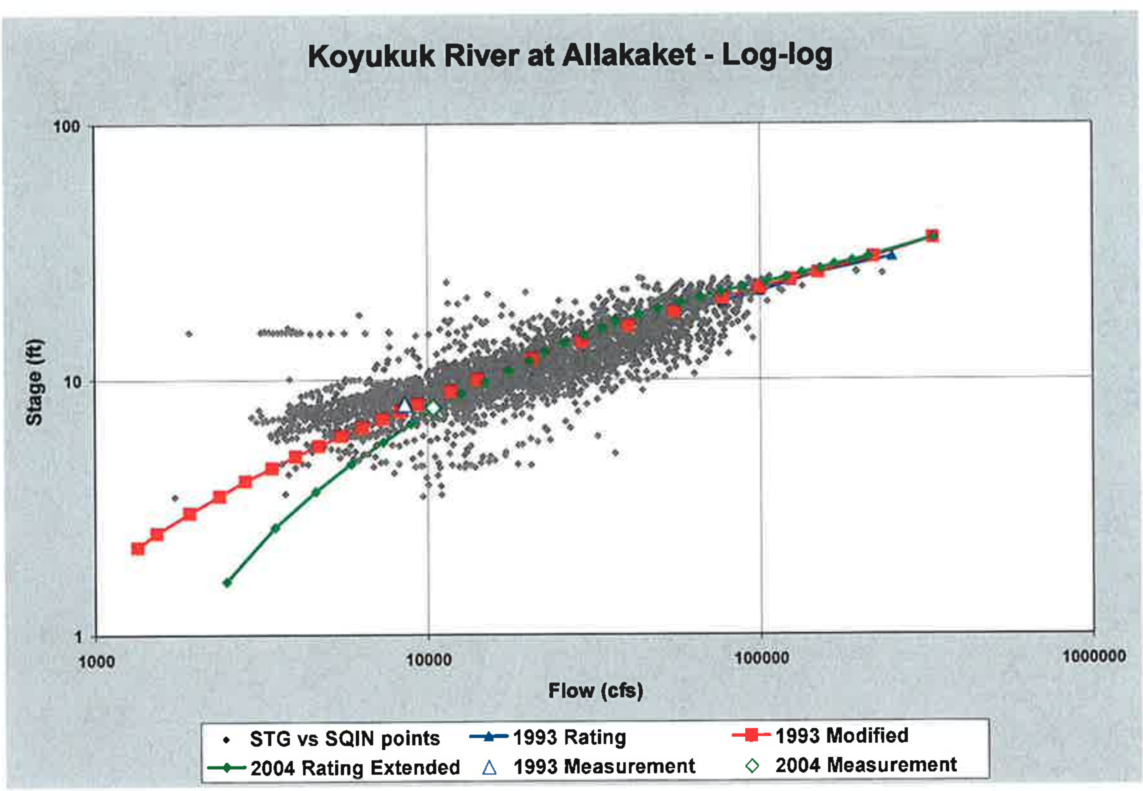

Figure 7b. Koyukuk at Allakaket stage versus flow – log-log scale.

Watershed	MFKA2	JMRA2	SLAA2	KRHA2
Period	WY 1977-87	WY 71-77	WY 96-2002	WY 1963-82
Overall Bias - %	8.16	5.05	-3.15	-0.99
Daily RMS/ $\overline{Q}$	1.03	1.19	0.90	0.82
Monthly Vol. RMS/ $\overline{V}$	0.46	0.52	0.41	0.41
Correlation Coef.	0.844	0.827	0.851	0.882
Slope – Best fit line	0.823	0.819	0.940	0.876
Sim/Obs Peak ratio	0.79	0.65	0.89	0.78

Table 4. Summary calibration statistics.

	First Storm					Second Storm					
	16	17	18	19	Total	24	25	26	27	28	Total
BTTA2	.88	2.96	.09	0	3.93	.93	.79	1.04	.27	.01	3.04
ATGA2	0	.7	.6	.5	1.8						3.9
PALR	.03	.32	0	0	.35	0	.62	.57	.56	0	1.75
CDXA2					4.7						5.2
HOZA2	0	.32	.21	.01	.53						msng
KANA2	0	.21	.19	0	.40	0	.29	.42	.27	.03	1.01
NRUA2	.19	1.68	1.61	.13	3.59	0	.89	.79	1.39	.14	3.31
HOGA2	.07	2.07	2.32	.04	4.50	.01	1.05	1.42	1.41	.44	4.38
TOOA2	.2	.3	0	0	.5	.1	0	0	0	0	.1
Tanana	.11	.71	0	0	.82	.47	.70	.55	.19	.06	1.97
FAI	0	.10	0	0	.10	.28	.76	0	0	0	1.04

Table 5. Observed precipitation data for the August 1994 flood (inches).

Watershed	Observed Values			Simulated Values	
	Day	Stage (ft)	Est. Flow (cfs)	Day	Flow (cfs)
MFKA2				8/17	16,100
	8/27	12.9	42,700	8/26	35,700
JMRA2				8/18	39,500
				8/26	25,900
SLAA2				8/17	4,900
				8/25	5,100
BTTA2	8/18	21.6		8/18	70,500
	8/28	23.9		8/27	108,000
ALLA2	8/19	26.3		8/19	243,000
	8/29	35.6	333,000	8/29	336,000
KRHA2				8/21	229,000
	8/31	34.6	330,000	8/31	326,000

Table 6. Observed and simulated values for the August 1994 flood.

	MFKA2 (wy 73-87)			JMRA2 (wy 71-77)			KRHA2 (wy 63-82)		
	all	gages	reanal	all	gages	reanal	all	gages	reanal
Overall Bias %	8.16	7.7	8.0	5.05	4.8	5.7	-0.99	-0.99	-1.25
Daily RMS/$\overline{Q}$	1.03	1.04	1.07	1.19	1.17	1.40	0.82	0.79	0.89
Monthly RMS/$\overline{V}$	0.46	0.47	0.47	0.52	0.53	0.58	0.41	0.43	0.43
Correlation Coefficient	0.844	0.842	0.823	0.827	0.839	0.750	0.882	0.892	0.855
Slope – Best fit line	0.823	0.820	0.823	0.819	0.812	0.786	0.876	0.868	0.884
Sim/Obs Peak ratio	0.79	0.81	0.72	0.65	0.69	0.54	0.78	0.83	0.75

Table 7. Summary statistics when using different temperature networks.

Appendix A – Contents of Koyukuk Basin Calibration CD

Introduction

The CD for the Koyukuk Basin calibration contains this report, all the program input and time series files, spreadsheet files, and some miscellaneous information. There are 4 main directories/folders on the CD. These are:

1. Report – copy of this report,
2. Excel Files – all spreadsheet files,
3. Data Files – program input files and all time series files, and
4. Misc Files – scanned copies of temperature versus elevation plots and copy of the 1994 flood report.

The items in the Report and Excel Files directories were generated on a PC running Windows XP Professional Version. The items in the Data Files directory were generated on a Linux PC and transferred to the windows machine before being copied to the CD. This appendix contains a detailed description of the contents of each major directory.

Report Directory

This directory contains this report generated using Microsoft Word 2002.

Excel Files Directory

This directory contains the spreadsheet files generated as part of the historical data analysis and model calibration effort and those files generated by the APRFC in support of the project. The APRFC files are included for completeness.

Files generated during the calibration (produced using Microsoft Excel 2002):

- Basic Information Summary.xls – contains:
  - computation of the drainage areas for each sub-basin,
  - mean elevations, average precipitation, and fraction of the sub-basin for each elevation zone,
  - unit hydrograph computations (adjustment of GIS UHGs to final drainage area, and generation of attenuated UHGs that were used at one point in the calibration),
  - ET-Demand computations for each area, and
  - mean monthly max/min temperatures for each area.
- Koyukuk_precipitation_analysis.xls – contains:
  - comparison of PRISM and PXPP average values, and
  - computation of station weights for each area.
- Koyukuk_avg_temps.xls – contains:
  - computation of average monthly max/min temperatures for each station, and
  - final lapse rates for each month.

- Evaporation Analysis.xls – contains computations for steps 1-5 described in the Historical Data Analysis – Evaporation section of the report.
- MFKA2_STG_vs_SQIN.xls – contains simulated flow versus observed stage comparisons and rating curves for the Middle Fork of the Koyukuk River near Wiseman.
- BTTA2_STG_vs_SQIN.xls – contains simulated flow versus observed stage comparisons and rating curves for the Koyukuk River at Bettles.
- ALLA2_STG_vs_SQIN.xls – contains simulated flow versus observed stage comparisons and rating curves for the Koyukuk River at Allakaket.

Files generated by Scott Lindsey of the APRFC:

- Koyukuk_watershed_info.xls – contains basic information derived from a GIS for each sub-basin and elevation zone including mean elevation, area versus elevation curves, PRISM precipitation values, and percent forest.
- uhg.IHABBS.qpw – Corel Quattro Pro file containing GIS based unit hydrographs for each sub-basin except the Kanuti River.
- Bettles_rating_and_survey_info.xls – contains cross-sections, rating curves, and photographs for the Koyukuk at Bettles.
- Allakaket_rating_and_survey_info.xls – contains cross-sections, rating curves, and photographs for the Koyukuk at Allakaket.
- Hughes_rating_and_survey_info.xls – contains cross-sections, rating curves, and photographs for the Koyukuk at Hughes.

Data Files Directory

This directory contains all of the program input files, station data files, and sub-basin time series files used for the historical data analysis. There are 8 sub-directories.

- Station_pcpn – contains the precipitation time series for each station used to generate MAP time series, plus a README.edits file containing descriptions of edits to the data records.
- Station_tempt – contains the max and min temperature time series for the stations, Reanalysis locations, and the Fairbanks radiosonde, plus a README.edits file.
- PXPP_input – contains input files for the PXPP runs made for the 3 different time periods described in the report.
- MAP_input – contains 2 input files for the MAP program; one file is to check the consistency of the station data and the other file is for generating MAP time series.
- MAT_input – contains 5 input files for the MAT program; 2 to check the data consistency (one for stations and one for upper air locations) and 3 for generating MAT time series (one for each of the sets used – ‘all’, ‘gages’, and ‘reanal’)
- TAPLOT_input – contains 3 input files for the TAPLOT program; one for all stations and selected upper air sites, one for some stations and more upper air sites, and one with just a few stations and most upper air sites.

- MCP_input – contains 8 sub-directories with input for the MCP program; 6 are for locations with some observed river data (mfka2, jmra2, slaa2, btta2, alla2, and krha2), one is for snow model comparisons with snow measurements (snow), and one is for comparison plots of daily flow data scaled to a common drainage area (qmeplot) – except for the 'qmeplot' sub-directory each contains 4 decks labeled 'all', 'gages', 'reanal', and 'curr' (each deck is the same except for the file name of certain input and output time series – the 'curr' deck is the same as the 'all' deck – the 'snow' sub-directory doesn't contain a 'reanal' deck).
- Area_time_series – contains 12 sub-directories with all the time series used by ICP/MCP for each of the 11 sub-basins with the Koyukuk (mfka2, slaa2, knfa2, btta2, jona2, jmra2, sfka2, alaa2, alla2, knra2, and krha2) and for the snow comparison sites (snow) – time series with a 'g' at the end of the name are for the runs using MAT time series produced using only station data and those with a 'r' at the end of the name are for the runs using MAT values generated only from Reanalysis data.

Misc Files Directory

This directory contains scanned copies of the TAPLOT output with hand drawn lines used to define the temperature versus elevation relationship for each month. On the first sheet is a list of the data sites used and a color coded legend identifying each of the lines on the monthly plots. This directory also contains a Corel WordPerfect copy of the report on the August 1994 Flood by Meyer and Lindsey.